Chapter 2
The Deep Space Network: A Functional Description

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All deep-space missions—defined as those operating at or beyond the orbit of the Earth's Moon—require some form of telecommunications network with a ground system to transmit to and receive data from the spacecraft. The Deep Space Network or DSN is one of the largest and most sophisticated of such networks.

NASA missions in low Earth orbit communicate through either the Near Earth Network (NEN) or the SN (Space Network), with the SN, both operated by the NASA Goddard Space Flight Center (GSFC). The SN has of a number of Tracking and Data Relay Satellites (TDRS) in geosynchronous orbits. In addition, the European Space Agency operates a number of ground stations that may be used to track NASA deep space missions during the hours after launch. In addition, commercial companies operate ground stations that can communicate with NASA missions. The remainder of this book describes only the Deep Space Network operated for NASA by JPL.

The lessons and techniques of the DSN replicate many comparable issues of the other networks. The lessons from the missions described in the following chapters are widely applicable to all deep space telecommunications systems. This includes post-launch support that was negotiated and planned using stations belonging to networks other than the DSN.

The description and performance summary of the DSN in this chapter come from the *DSN Telecommunications Link Design Handbook*, widely known

within NASA as the 810-5 document [1]. This modular handbook has been approved by the DSN Project Office, and its modules are updated to define current DSN capabilities. It is an online source of technical information for all flight projects using the DSN. The following description is taken from 810-5 modules that provide technical information applicable to the current DSN configurations that provide carrier tracking, radiometric data, command transmission and telemetry reception.

The DSN is an international network of ground stations (antennas, transmitters, receivers, and associated systems) that operated intensively at S-band in the 1960s and 1970s, moving into X-band in the 1980s and 1990s, and more into Ka-band in the 2000s. The DSN supports interplanetary-spacecraft missions and radio- and radar-astronomy observations for the exploration of the Solar System and beyond. The DSN consists of three Deep Space Communications Complexes (DSCCs) placed approximately 120 degrees (deg) apart around the world: at Goldstone, in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia.

The DSN's hardware and software systems and their interconnected facilities have evolved over the decades. This chapter describes the DSN as it is today. The subsequent chapters describe the spacecraft designs of individual missions. Each chapter includes a description of the unique aspects of the ground system that supported the mission at that time.

Because each mission is unique, the telecommunications system for the mission is also unique. While the subsequent chapters describe the spacecraft designs of individual missions, these chapters will describe only the historical or unique aspects of the ground system as it supported that mission at the time.

This chapter includes brief descriptions and functional block diagrams of DSN systems at the DSCCs that provide carrier tracking, radiometric data (Doppler and ranging) collection, command uplinking, and telemetry reception and decoding for deep space missions, those defined at lunar distances or greater.

Each antenna (or Deep Space Station, DSS) in the DSN is capable of sending commands to one spacecraft at a time. Each DSCC contains one 70-meter (m) and from two to five 34-m antennas. There are two types of 34-m antennas. The first is the so-called high efficiency (HEF) antennas that have their feed, low-noise amplifiers, and transmitter located on the tilting structure of the antenna. These antennas were named when a less-efficient 34-m antenna was in use by the DSN and the name has survived. The efficiency of all DSN 34-m antennas is now approximately the same. The second type of 34-m antenna is the beam waveguide (BWG) antenna where the feeds, low-noise amplifiers and

transmitters are located in a room below the antenna structure and the radio frequency energy is transferred to and from the antenna surface by a series of mirrors encased in a protective tube.

The capabilities of the antennas differ slightly depending on the microwave, transmitting, and receiving equipment installed.

2.1 Uplink and Downlink Carrier Operation

DSN stations are grouped by antenna size (26 m, 34 m, and 70 m), and for the 34-m antennas by type—BWG or HEF. The *DSN Telecommunications Link Design Handbook* [1] includes functional capability descriptions of each antenna size and type for the purpose of modeling link capability between a spacecraft and that station type.

2.1.1 The 34-m BWG Stations

The 34-meter diameter BWG (beam waveguide) and HSB (high angular-tracking speed beam waveguide) antennas are the latest generation of antennas built for use in the DSN. The newest of these, Deep Space Station 35 (DSS-35) at Canberra, is on schedule to be operational in October 2014. This section describes, as representative of the 34-m stations, the system functions at Deep Space Station 25 (DSS-25), a 34-m BWG station currently in use at Goldstone.

In general, each antenna has one LNA for each supported frequency band. However, stations that can support simultaneous right circular polarization (RCP) and left circular polarization (LCP) in the same band have an LNA for each. In addition, the stations that support Ka-Band contain an additional LNA to enable monopulse tracking when using RCP polarization. Each antenna also has at least one transmitter. Antennas with more than one transmitter can operate only one of them at a time.

DSS 25 is an exception and has a Ka-band transmitter that can be operated at the same time as its X-band transmitter. In Fig. 2-1, the radio frequency (RF) output from the 20-kW X-band transmitter goes through the X-band diplexer, then through an orthomode junction and polarizer to the X-band feed. The X-band uplink continues to the subreflector via an X-band/Ka-band dichroic plate, if simultaneous Ka-band is required. From the subreflector, the X-band uplink is focused to the 34-m main reflector, which is oriented in the direction of the spacecraft during the active track.

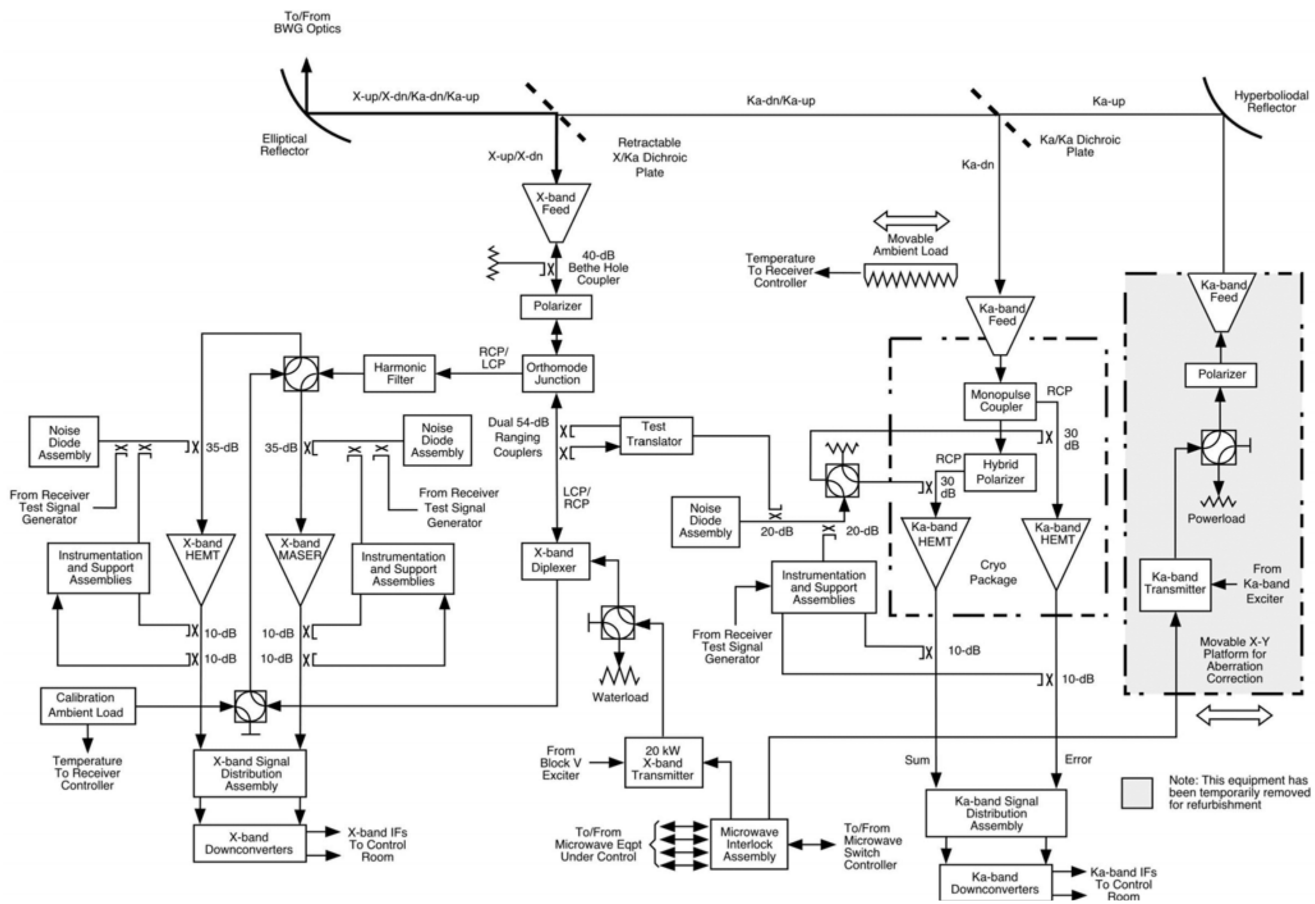


Fig. 2-1. Functional block diagram of the DSS-25 microwave and transmitter. (A new Ka-band transmitter will go into service in 2015.)

The X-band downlink signal from the spacecraft is collected by the 34-m main reflector. Then it is focused by the subreflector to the X-band feed (again via the X-band/Ka-band dichroic when there is also a Ka-band downlink from the spacecraft). The orthomode junction is the part of the antenna feed that combines or separates left-circularly polarized and right-circularly polarized (LCP and RCP) signals. From the feed the X-band RF signal goes to the X-band maser preamplifier.

When simultaneous X-Band uplink and downlink of the same polarization are required at stations with waveguide diplexers, reception must be through the diplexer, and the noise will be increased over that of the non-diplexed path.

After low-noise amplification, the downlink is frequency down-converted to a 300-megahertz (MHz) intermediate frequency (IF) for input to the Block V Receiver (BVR). All DSN antennas employ a receiver architecture where one or both circular polarizations of the received spectrum are amplified by a low-noise amplifier (LNA) and downconverted to IF. The antennas are designed to receive extremely weak signals and can be overloaded by signals in excess of –90 dBm. Antennas supporting 26 gigahertz (GHz) have a special low-gain mode that permits operation up to –50 dBm with degraded G/T.

The Ka-band downlink also is collected by the 34-m main reflector and focused by the subreflector. It passes through the dichroic plate to separate it from the X-band downlink signal path, on its way to the Ka-band feed. DSS-25 is equipped for RCP or LCP at Ka-band. The Ka-band preamplifier is a high-electron-mobility transistor (HEMT). Like the X-band downlink, after low-noise pre-amplification, Ka-band downlink is frequency down-converted for input to the BVR.

2.1.2 The 70-m (DSS-14 and DSS-43) Stations

Figure 2-2 shows the antenna, microwave and transmitter sections of the 70-m stations, DSS-14 and DSS-43.

The 20-kW X-band transmitter output goes through a polarizer and a diplexing junction to the X-band feed. From there, it passes through an S-band/X-band dichroic reflector on its way to the subreflector and the main 70-m reflector that sends the uplink on its way to the spacecraft.

The S-band uplink carrier, modulated with a command subcarrier when required, can be transmitted by a 20-kW transmitter or (at DSS-43 only) a 400-kW transmitter. The transmitter output goes through an S-band diplexer, orthomode junction and polarizer to the S-band feed. From there, as the block diagram shows, the S-band uplink path is via three smaller reflectors and the 70-m reflector before radiation to the spacecraft.

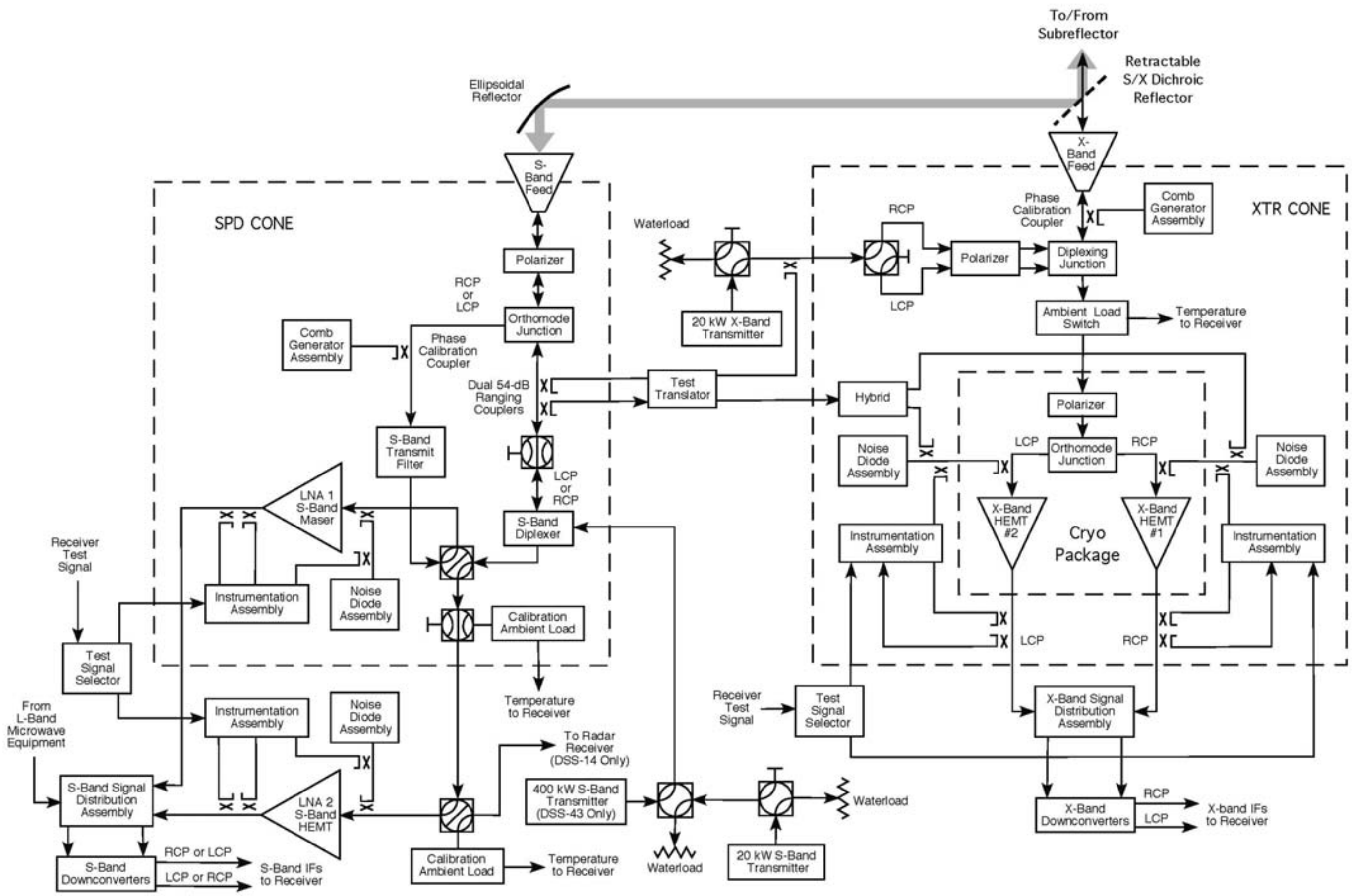


Fig. 2-2. Functional block diagram of 70-m microwave and transmitter.

The X-band downlink from the main reflector is focused by the subreflector and passes through the dichroic reflector to separate it from the S-band signal path. From the diplexing junction, the X-band downlink goes to a polarizer to select (match) the left circular or right circular polarization of the downlink transmitted from the spacecraft. The X-band downlink from the X-band HEMT preamplifier is frequency-downconverted for input to the BVR.

From the 70-m reflector, the S-band downlink is directed by the subreflector to the S/X dichroic reflector. A dichroic surface is reflective at one frequency band and transparent at another, thus allowing the S-band frequencies to be separated from X-band frequencies for individual processing. The dichroic reflects the S-band downlink to the path shown by the thick line in the block diagram to the S-band feed. Reversing the path taken by the uplink, the downlink is directed by the diplexer to an S-band maser preamplifier, and its frequency is down-converted for input to the block V receiver (BVR).

2.2 Radiometric Data (Doppler and Ranging)

The relative motion of a transmitter and receiver causes the received frequency to differ from that of the transmitter. In deep space communications it is usual to define Doppler as the transmitted frequency (the uplink) minus the received frequency (the downlink) divided by the ratio that was used onboard the spacecraft (the transponding ratio) to generate the downlink frequency. Because the frequency of a carrier equals the rate-of-change of carrier phase, the Downlink Channel supports Doppler measurement by extracting the phase of the downlink carrier.

There are three types of Doppler measurement: one-way, two-way, and three-way. One-way refers to the radio-frequency (RF) carrier frequency being generated by an on-board oscillator in the spacecraft and received at the station. Two-way refers to the carrier being generated at the station, transmitted to a coherent transponder in the spacecraft, transmitted from the transponder and received back at the transmitting station. Three-way is the same as two-way, except that the downlink carrier is received at a second ground station, either in the same DSN complex or at another complex. In all of these cases, the accumulating downlink carrier phase is measured and recorded. Because ground-station oscillators have greater frequency stability than spacecraft oscillators, two-way or three-way Doppler measurements are used in deep space navigation.

At the station, the two-way downlink signal from the spacecraft is routed from the antenna feed/low-noise amplifier (LNA) to the downlink channel, as shown in Fig. 2-3. If the downlink is one-way, the uplink sections at the bottom of the

figure do not play a part. Within the RF to intermediate-frequency downconverter (RID), which is located at the antenna, a local oscillator is generated by frequency multiplication of a highly stable frequency reference from the frequency and timing system (FTS) and the incoming downlink signal is heterodyned with this local oscillator. The intermediate-frequency (IF) signal that results is sent to the signal processing center (SPC).

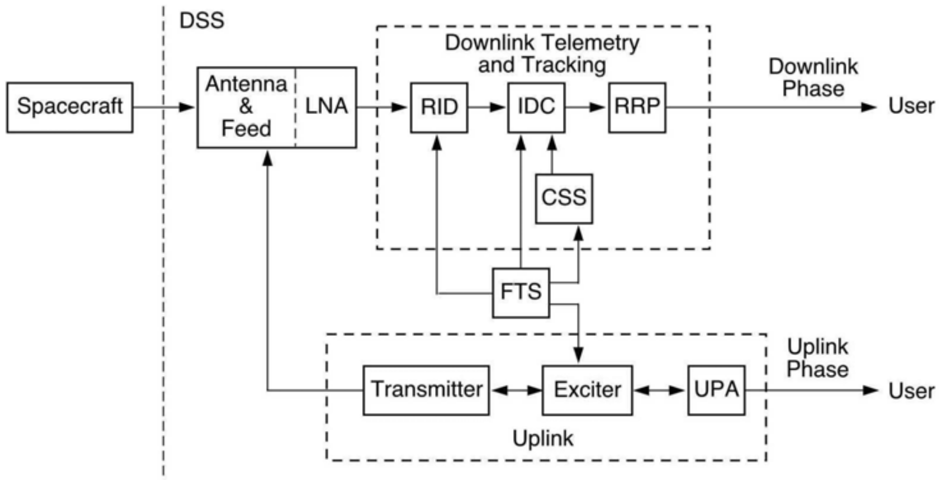


Fig. 2-3. Two-way or three-way Doppler measurement.

Two-way or three-way Doppler data points consist of uplink and downlink phase counts at sky frequency (only downlink phase counts in the case of a one-way measurement). The downlink phase counts are available at 0.1-second (s) intervals. The uplink phase counts are available from the uplink processor assembly (UPA) at 1.0-s intervals.

The Doppler measurements establish the spacecraft-station velocity as a function of time and can be compared with the expected or modeled velocity. This velocity measurement includes the motion of the station in inertial space due to the Earth's rotation.

The DSN ranging system measures the round-trip phase delay of a ranging signal sent from an uplink DSS to a spacecraft and back to a downlink DSS. In the most common configuration, known as two-way ranging, the uplink and downlink stations are the same, and the measured two-way phase delay permits the determination of the round-trip light time (RTLT) between the DSS and spacecraft.

A range measurement may be made with a constant uplink carrier frequency or when the transmitted uplink carrier frequency is time varying. For some missions, it is desirable to anticipate the uplink Doppler effect and to transmit an uplink carrier whose frequency varies in such a way that the uplink carrier arrives at the spacecraft with minimal offset from channel center. This is called uplink Doppler compensation and has the advantage of reducing the stress on the carrier tracking loop in the spacecraft receiver. The DSN ranging system accommodates either time-varying or constant transmitted uplink frequency.

The architecture for the DSN ranging system is shown in Fig. 2-4. The system consists of a front-end portion, an uplink subsystem (UPL), and a downlink telemetry and tracking subsystem (DTT). The front-end portion includes the microwave components, including a low-noise amplifier (LNA), the transmitter, and the antenna. The UPL includes the uplink ranging assembly (URA), the exciter, and their controller, referred to as the uplink processor assembly (UPA). The DTT includes a downconverter (the RID) located on the antenna, the IF-to-digital converter (IDC), the receiver and ranging processor (RRP) and the downlink channel controller (DCC).

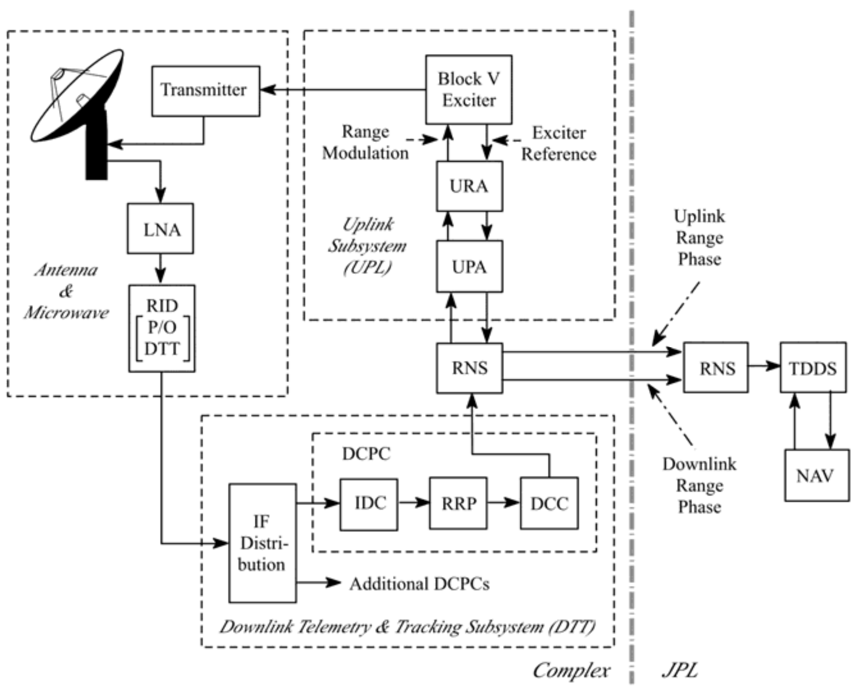


Fig. 2-4. The DSN ranging system architecture.

The uplink ranging assembly (URA) uplink ranging function is controlled by the UPA. The RRP downlink ranging function is controlled by the DCC. Each measures the range phase and sends the measurements to the tracking data delivery subsystem (TDDS) via the reliable network service (RNS). The URA generates the uplink ranging signal and measures its phase before passing it to the exciter. The signal is phase-modulated onto the carrier by the exciter and, after being amplified to a suitable level by the transmitter, is forwarded to the spacecraft. The spacecraft coherently transponds the signal, sending it back to the DSN receiver.

The amplified downlink signal from the antenna is downconverted by the RID (located on the antenna) and fed to an intermediate frequency (IF) distribution assembly in the control room. The IF is fed to one or more downlink channel processing cabinets (DCPCs) as required. Each DCPC is equipped with a single channel, which includes a single IDC and RRP. For a spacecraft that requires ranging on multiple downlinks (for example, S-band and X-band), multiple DCPCs will be assigned to that antenna.

Three-way ranging is accomplished in essentially the same way as two-way ranging, except that there are two stations. The UPL, transmitter, and antenna of one DSS are used to transmit an uplink carrier modulated with a ranging signal. The uplink range phase is recorded at that station. At a second DSS, the antenna, LNA and DTT receive the downlink from the spacecraft and record the downlink range phase.

The sequential ranging signal is a sequence of periodic signals. These periodic signals are all coherently related to each other and to the uplink carrier. The basis for these periodic ranging signals is a table of well-defined range components. Each component is assigned a number. A larger number represents a component with a smaller frequency (but a larger period). The components that are used in ranging are assigned the numbers 4 through 24 and are ordered according to these component numbers. The frequency of component 4 is always approximately 1 MHz, and it is often called the “1 MHz component” and used as the “clock.” The frequency of components 5 through 24 is exactly half of their immediate predecessor.

At JPL, the radiometric data conditioning group, part of the multimission navigation function, processes and delivers the Doppler and ranging data to project navigation. The radio-navigation data sets are also used to generate prediction files (P-files) for delivery back to the DSN, for use in creating the frequency and pointing predicts for subsequent tracking passes. Frequency predicts are input to the BVR to assist in locking the receiver to expected periods of one-way, two-way, or three-way data. Pointing predicts are used to

drive the station antenna in elevation and azimuth angle during the pass. Pointing predicts are supplemented by several tables specific to the station type, location, and the general declination of the spacecraft. These supplementary tables include corrections for atmospheric refraction as a function of elevation angle and azimuth as well as for deformation of the antenna structures (and thus, changes in the beam direction) as a function of elevation angle.

2.3 Delta Differential One-Way Ranging

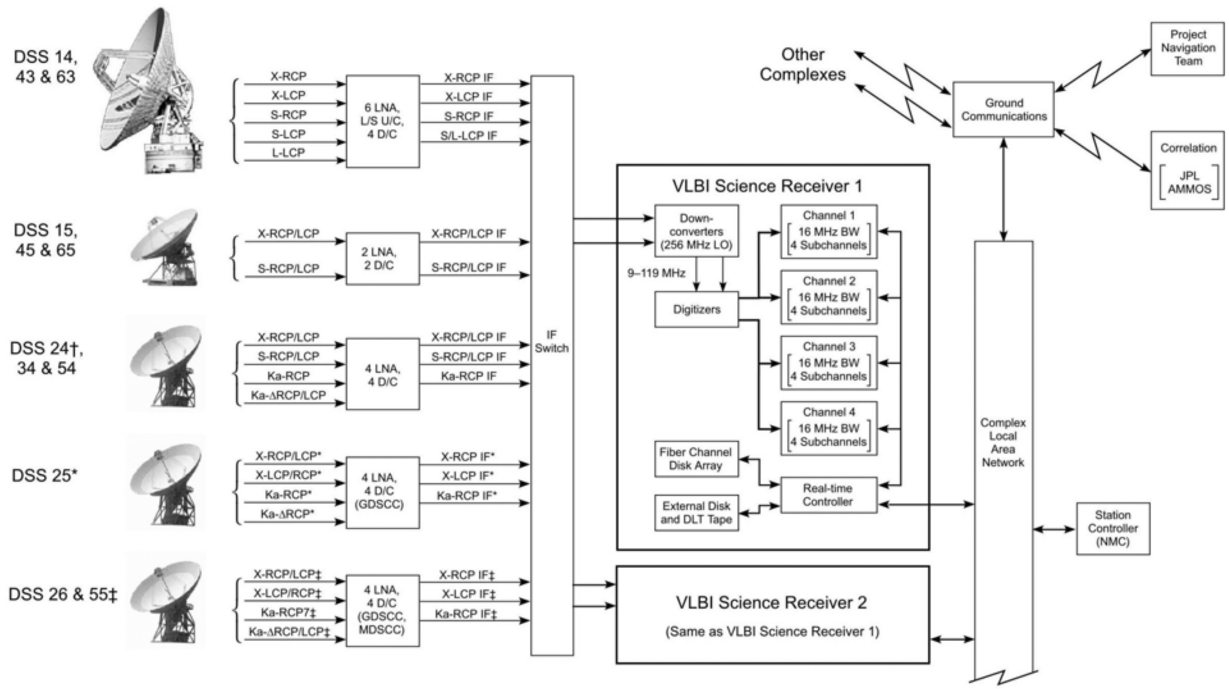
Delta-differential one-way ranging (delta-DOR) is a very long baseline interferometric (VLBI) radio-tracking technique using two deep-space stations located at different complexes for a single measurement. It uses the differential one-way range technique to provide information about the angular location of a target spacecraft relative to a reference direction where the reference direction is defined by the direction of arrival of radio waves from a distant known source, such as a quasar, whose direction is well known and catalogued.

Delta-DOR provides a direct geometric determination of spacecraft angular position and is therefore especially useful when line-of-sight measurements (Doppler and ranging) have weaknesses such as spacecraft traveling near zero declination and spacecraft with small, unmodeled dynamic forces affecting their motion. Another advantage of delta-DOR is that measurements are of relatively short duration (approximately 1 hour) as compared with the hours of tracking typically required for Doppler and ranging.

Measurements are conducted using either the Goldstone-Madrid baseline or the Goldstone-Canberra baseline. Two baselines with orthogonal components are needed to measure both the right ascension and declination coordinates of angular position. The Goldstone–Madrid baseline is oriented east–west and is most sensitive to right ascension for spacecraft near the ecliptic plane. The Goldstone–Canberra baseline is canted and has most sensitivity in the direction that splits the axes of right ascension and declination.

Differential one-way ranging is supported by the 34-m and 70-m antennas. Other equipment includes the VLBI science receivers (VSRs) in the signal processing center (SPC), the ground communications infrastructure, and the DOR correlator at JPL. Figure 2-5 shows the DSN equipment used.

Planning a measurement involves scheduling the stations and identifying the appropriate distant reference sources. The spacecraft's contribution to making a delta-DOR measurement is to provide a one-way downlink carrier modulated by a set of continuous-wave tones. The "delta DOR module" in the Small Deep-Space Transponder (SDST) generates a tone at approximately 19.1 MHz.



* Equipment or interface only exists at Goldstone DSCC

‡ Equipment or interface only exists at Goldstone and Madrid DSCCs

† DSS 24 is not recommended for ΔDOR measurements.

Fig. 2-5. DSN equipment for delta-DOR support.

On many projects, Navigation also requests that a telemetry subcarrier (preferably without telemetry symbols) modulate the downlink carrier to provide a second delta-DOR “tone.” Though subcarrier frequencies in the range of 375 kilohertz (kHz) are preferred for this purpose, some projects provide a subcarrier frequency in the range of 25 kHz. A subcarrier modulation index of about 30 deg provides a good balance of power between the carrier the delta-DOR tone and the subcarrier “tone.”

2.4 Command Processing and Radiation

Uplink data are delivered to the DSN using one of three services, named stream mode radiation, file mode radiation, and command delivery.

Stream mode command radiation uses the space link extension (SLE) forward service, an implementation of the Consultative Committee for Space Data Systems (CCSDS) recommendation 912.1, SLE command link transmission unit (CLTU) Service [2], and is described in DSN Document 820-013, module 0163-Telecomm [3], an internal JPL document. The SLE forward service is an online only service in which the service users (flight projects) provide command symbols to be transferred to the spacecraft and ancillary information such as routing, ensuring the integrity of the Earth segment of the communications link, and providing the project limited control of the command process.

File mode command radiation accesses a file of CLTUs from project’s mission support area via DSN File Store where the individual CLTUs are extracted and passed on to the station for modulation onto the uplink carrier and radiation to the spacecraft. The file of CLTUs is referred to as a spacecraft command message file (SCMF). Refer to Fig. 2-6 for “file mode” data flow. This service is an online or offline store and forward service that allows management of multiple stored command files.

Command delivery service, uses the CCSDS file delivery protocol (CFDP) and is available for spacecraft that employ this protocol. It is described in Ref. [4]. The service is provided by accessing files from the MSA via DSN file store where the files are converted to CLTUs, which are then passed to the tracking station for modulation onto the uplink carrier and radiation to the spacecraft. As shown in Fig. 2-7, the only function performed at the stations is the mechanism whereby command data are extracted from the delivery format and converted to an RF signal suitable for reception by the spacecraft.

In the mission support area, the project ACE (call sign for project real-time mission controller) operates the multimission command system from a workstation. An ACE is able to activate command transmission within 2 s of

the nominal time. To begin or end a command session, the ACE requests the station to turn the command modulation on or off, respectively.

The RNS transfers the command files to the station in the staging process, as well as the ACE directives for radiation of the staged commands. At the station, the command processor assembly (also part of the "service provider") performs the digital processing to create the command-bit stream from the command files and the activation signal.

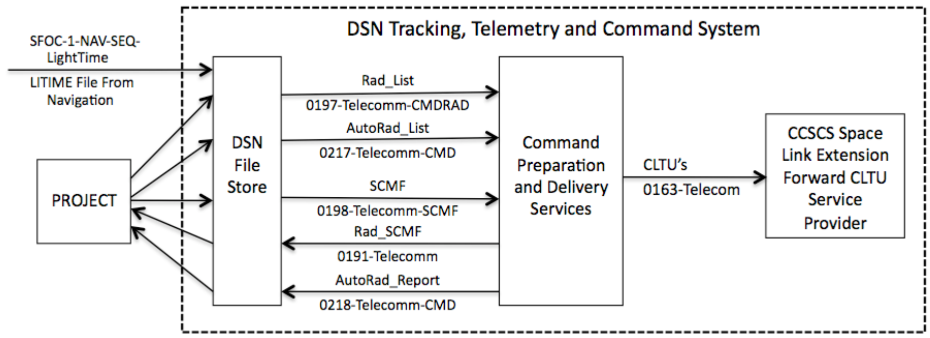


Fig. 2-6. Command radiation service data flow for "File Mode" (SCMF).

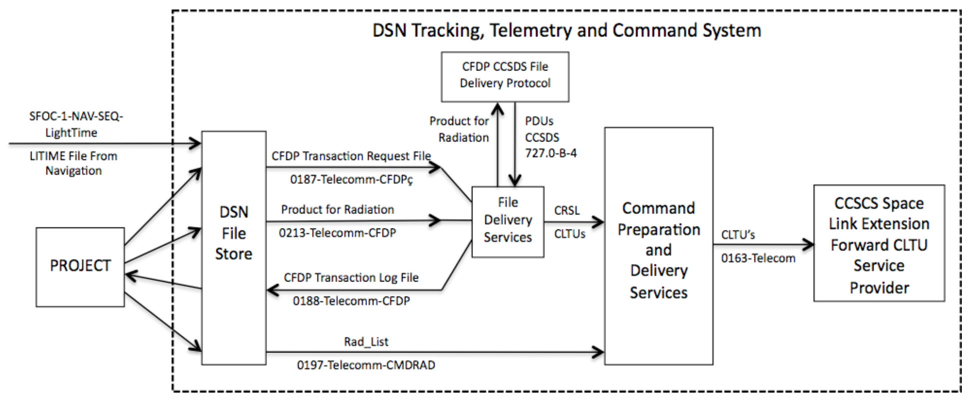


Fig. 2-7. Command delivery service (CFDP) data flow (see Ref. 13 regarding 727.0B-4).

2.5 Telemetry Demodulation and Decoding

In general, telemetry service support requires one antenna, at least one receiver, and telemetry processing equipment for each spacecraft. Additional receivers and telemetry processing equipment can be added for spacecraft with multiple

downlinks or for redundancy. In addition, the DSN is capable of tracking two spacecraft per antenna (multiple spacecraft per aperture, MSPA) if they both are within the scheduled antenna's beamwidth.

The telemetry system performs three main functions: data acquisition, data conditioning and transmission to projects, and telemetry-system validation. Data acquisition includes receiving and tracking the downlink carrier and subcarrier (if used), detecting and synchronizing the telemetry symbols, and decoding the symbol stream for input into telemetry frames. These functions are within the "downlink channel" block in Figs. 2-8 and 2-9.

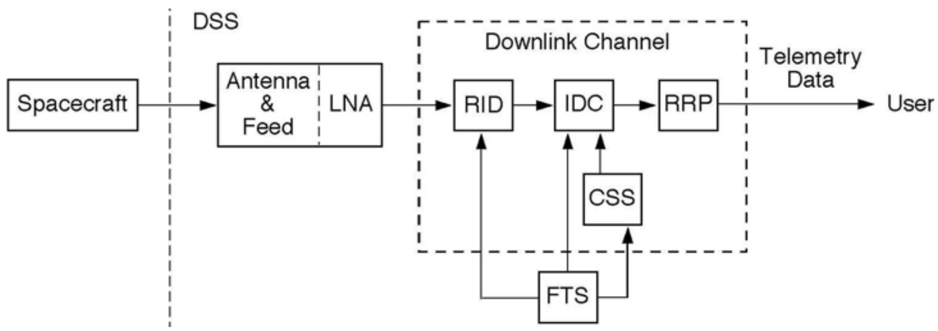


Fig. 2-8. Receiver architecture for downlink telemetry.

As described for downlink carrier tracking, the arriving signal is routed from the antenna feed and LNA to the downlink channel. After the frequency-downconverted IF signal reaches the SPC, the intermediate-frequency to digital converter (IDC) alters the frequency of the IF signal by a combination of up-conversion and down-conversion to a final analog frequency of approximately 200 MHz and then performs analog-to-digital conversion. The final analog stage of down-conversion uses a local oscillator supplied by the channel-select synthesizer (CSS), which is also part of the downlink channel.

The channel select synthesizer (CSS) is adjusted before the beginning of a pass to a frequency appropriate for the channel of the incoming downlink signal; during the pass, the frequency of the CSS remains constant. The frequency of the CSS (and, indeed, of all local oscillators in the analog chain of downconversion) are synthesized within the downlink channel from highly stable frequency references provided by the frequency and timing system (FTS). The receiver and ranging processor (RRP) accepts the digital signal and performs carrier, subcarrier, and symbol synchronization, Doppler compensation, and data demodulation. For purposes of telemetry, the output of the RRP is a stream of soft-quantized symbols, suitable for input to a decoder.

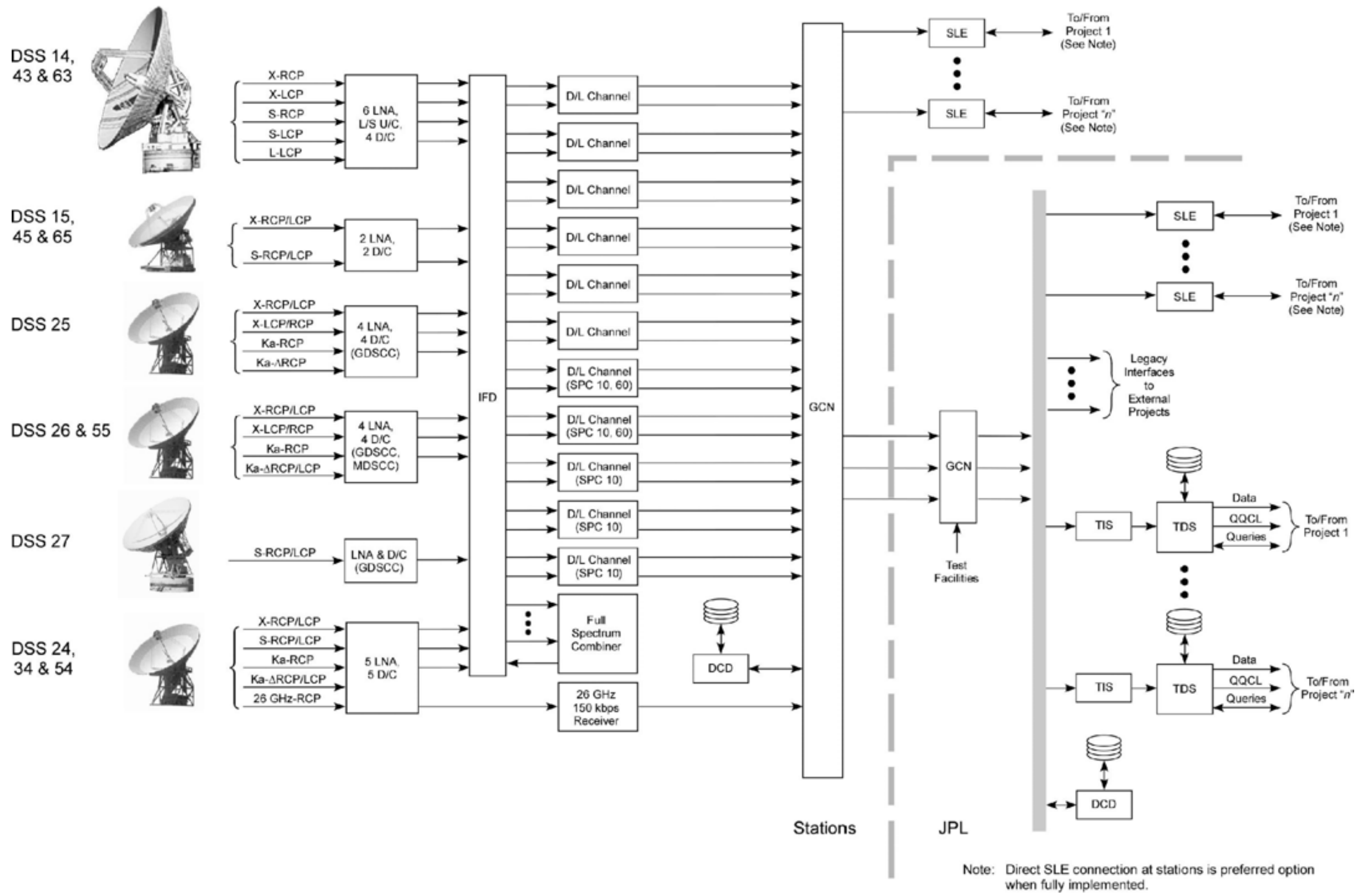


Fig. 2-9. DSN telemetry equipment for spacecraft support.

Almost all spacecraft employ forward error-correcting (FEC) codes to make more efficient use of the communications channel. FEC codes add additional symbols to the transmitted data stream that the decoder can use to improve its estimate of the encoded bit stream. The exceptions to FEC use would likely be extremely high data rate transmissions where adequate signal power is available to make the gain achieved by coding unnecessary and any bandwidth needed for the symbols added by coding is unavailable.

The DSN supports two convolutional codes, the Consultative Committee for Space Data Systems (CCSDS) standard Reed-Solomon code and the CCSDS Turbo codes. Convolutional codes are used because they achieve significant coding gain with simple, highly reliable encoders and their decoders are of reasonable complexity. They also provide low latency and are useful when conditions prevent reception of a block of symbols. The Reed–Solomon code provides excellent performance with minimum bandwidth expansion in a high signal-to-noise environment. It is most often used as an outer code in combination with a convolutional inner code but may be used by itself under appropriate signal conditions. Turbo codes provide near-Shannon-limit error-correction performance with reasonable encoding and decoding complexity.

Frame synchronization must be established before processing any block code such as Reed–Solomon or Turbo codes or before formatting the data for delivery. Synchronization is accomplished by preceding each code block or transfer frame with a fixed-length attached synchronization marker (ASM). This known bit pattern can be recognized to determine the start of the code blocks or transfer frames. It also can be used to resolve the phase ambiguity associated with binary phase-shift keying (BPSK) or quadrature phase-shift keying (QPSK) staggered-quadrature phase-shift keying or offset-quadrature phase-shift keying (SQPSK or OQPSK) modulation. The DSN contains two frame synchronizers. The first of these operates in the bit domain and is used with convolutionally coded, Reed–Solomon coded or uncoded data. The second operates in the symbol domain and is used with Turbo coded data.

The ground communications network (GCN) uses communications circuits provided by the NASA Integrated Services Network (NISN) to connect the stations to JPL Central and users. The DSN provides CCSDS SLE data delivery directly from the station at which it is received or through the DSN central facility at JPL. Data storage, buffering against line outages, access, retrieval, and query are provided at all locations. Data delivery for additional telemetry functions such as packet extraction and CFDP file processing is from the DSN central facility where these functions are performed.

The Advanced Multimission Operations System (AMMOS) processes telemetry in both near-real time (delays as long as 1 minute) and in nonreal time (as complete a record as possible, but with a delivery time guaranteed within 2 hours of the end of track). The non-real time version includes retransmission of data lost between the station and JPL and replays from the central data recorder (CDR) as necessary.

Telemetry processing by AMMOS at JPL includes “channelizing” the data from the packets received, ordering the telemetry data that may have been transmitted in real time or from spacecraft storage, and time-tagging the data either by Earth-received time (ERT) or spacecraft-event time (SCET). Starting in 2011, the MSL project was the first to use the Mission-data Processing and Control Subsystem (MPCS) rather than AMMOS for telemetry data storage, display, and query.

2.6 DSN Performance

This section summarizes the major uplink and downlink characteristics of the stations when operating in the DSN frequency bands. Tabulated values are for the 34-m BWG stations DSS-24 (S-band) and DSS-25 (X-band and Ka-band) at Goldstone and the 70-m station DSS-14 at Goldstone. Refer to the more detailed tables in 810-5 [1] for other stations and other parameters.

2.6.1 Antenna Gain

Acquisition (AC) aid antennas operate at X-band only and at downlink only (Table 2-1).

2.6.2 Transmitter Power

The 20-kW S-band and X-band transmitters (Table 2-2) can be operated at levels between 200 W and the full rated 20 kW.

Only DSS-43 has a 400-kW S-band transmitter. The Ka-band transmitter at DSS-25 can be operated at levels between 50 W and the 800 W maximum.

2.6.3 System Noise Temperature

These specific S-band values (Table 2-3 apply to DSS-24. The X-band and Ka-band values apply to DSS-25.

2.6.4 Thresholds and Limits

The downlink carrier acquisition and tracking threshold depends on the receiver bandwidth. Tracking bandwidths of less than 1 hertz (Hz) are not recommended, and this equates to a minimum downlink carrier power of about –172 dBm.

The recommended maximum downlink received total power at the station's low noise amplifier is –90 dBm.

The maximum uplink ranging carrier suppression for reliable operations is –6 decibels (dB). The minimum downlink ranging Pr/No for reliable operation is –8 decibel Hertz (dB-Hz).

The minimum recommended transmitter power for normal operations with a 20-kW transmitter is 2 kW. For the initial acquisition day, 200 W is often used.

Table 2-1. 34-m and 70-m antenna gain and beamwidth.

Station	Parameter	Unit	Value	Remarks
34-m BWG	Uplink gain	dBi	56.3	S-band
			67.1	X-band
			79.5	Ka-band
70-m	Uplink gain	dBi	63.0	S-band
			73.2	X-band
34-m BWG	Uplink 3 dB beamwidth	deg	0.263	S-band, DSS-24
			0.077	X-band
			0.016	Ka-band, DSS-25
70-m	Uplink 3 dB beamwidth	deg	0.128	S-band
			0.038	X-band
34-m BWG	Downlink gain	dBi	56.84	S-band DSS-24
			68.2 38.0	X-band main Ac aid
			78.9	Ka-band, DSS-25
70-m	Downlink gain	dBi	63.6	S-band
			74.6	X-band
34-m BWG	Downlink 3 dB beamwidth	deg	0.242	S-band DSS-24
			0.066 2.1	X-band main Ac aid
			0.017	Ka-band, DSS-25
70-m	Downlink 3 dB beamwidth	deg	0.118	S-band

Table 2-2. 34-m and 70-m transmitter power, EIRP and frequency bands.

Station	Parameter	Unit	Value	Remarks
34-m BWG	Power output	kW	20.0	S-band
			20.0	X-band
			0.8	Ka-band
70-m	Power output	kW	20.0 400	S-band main High power
			20.0	X-band
34-m BWG	EIRP	dBm	128.7	S-band
			139.6	X-band
			138.2	Ka-band
70-m	EIRP	dBm	135.6 148.7	S-band main High power
			145.8	X-band
34-m BWG	Frequency band	MHz	2110–2118	S-band DSS-24
			7149–7188	X-band
			34315–34415	Ka-band DSS-25

Table 2-3. 34-m and 70-m downlink system noise temperature and polarization.

Station	Parameter	Unit	Value	Remarks
34-m BWG	System noise temp (LNA1)	K	26.1 nondiplex	S-band
			33.5 diplex	DSS-24
			20.2 nondiplex	X-band main
			29.2 diplex	
			280	Ac aid
			27.9 Ka-only	Ka-band
			31.4 X/Ka	DSS-25
70-m	System noise temp (LNA1)	K	10.5 nondiplex	S-band
			15.0 diplex	DSS-14
			20.2 nondiplex	X-band
			29.2 diplex	
34-m BWG	Receive polarization		RCP or LCP	S-band
			RCP or LCP	X-band main
			RCP	Ac Aid
			RCP or LCP	Ka-band
70-m	Receive polarization		RCP or LCP	S-band
			RCP or LCP	X-band
34-m BWG	Frequency band	MHz	2200-2300	S-band DSS-24
			8400–8500	X-band
			31800–32300	Ka-band DSS-25

Terms: LCP = left circularly polarized; LNA1 = low-noise amplifier 1;
RCP = right circularly polarized

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